Laser Measurements of Soot and CO Production in Time-Varying, Hydrocarbon Diffusion Flames

Christopher R. Shaddix, David A. Everest, and Kermit C. Smyth
National Institute of Standards and Technology, Building and Fire Research Laboratory, Gaithersburg, MD 20899

ABSTRACT

Most combustion systems of practical interest involve hydrocarbon diffusion flames, in which chemical processes are strongly coupled to fluid mechanical mixing of the reactants through heat release. In complex flowfields, such as turbulent flames, many combinations of residence times, temperature histories, local stoichiometries, and strain rates exist which are not accessible in steady, laminar diffusion flames. One might anticipate that chemistry-flowfield interactions will have a dramatic impact whenever chemical reaction times are comparable to or slower than mixing rates. In particular, the rates of soot mass growth as well as of soot and carbon monoxide oxidation are relatively slow, and thus the production and emission of soot and CO should be strongly sensitive to the complex, time-varying flowfields present in flickering flames.

Our recent measurements reveal significant changes when steady and flickering laminar flames are compared under conditions where the mean fuel flow velocity is identical. Planar images of laser-induced fluorescence from OH• radicals and elastic scattering from soot particles have been obtained in time-varying diffusion flames burning in a co-flowing, axisymmetric configuration at atmospheric pressure. Quantitative measurements of soot volume fraction have been made using calibrated laser-induced incandescence for methane, propane, and ethylene fuels. When the tip of the flame is clipped (flickering conditions), the intensity of the light scattered by the soot particles increases by up to 37 times in methane flames, while the peak soot volume fraction rises by a factor of 5.3. For the more heavily sooting fuels the observed increases in soot concentration and soot scattering are substantially less dramatic, but visible emission of smoke occurs from the flickering propane and ethylene flames. OH• concentrations are observed to collapse when smoke is emitted. Since OH• is the primary oxidizer of both CO and soot in these flames, CO emission is also expected to increase strongly under flickering conditions. Future experiments will focus on quantitative CO laser-induced fluorescence imaging using two-photon excitation of the $B^1\Sigma^+$ state. These studies will help to elucidate the most important factors which control chemistry-flowfield interactions and pollutant formation in turbulent combustion.

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